THE BRITTLE-DUCTILE TRANSITION OF TUNGSTEN SINGLE CRYSTALS AT THE MICRO-SCALE

Johannes Ast, Empa, Swiss Federal Laboratories for Materials Science and Technology, Feuerwerkerstrasse 39, 3602 Thun, Switzerland
johannes.ast@empa.ch
Juri Wehrs, Swiss Federal Laboratories for Materials Science and Technology, Switzerland
Jakob Schwiedrzik, Swiss Federal Laboratories for Materials Science and Technology, Switzerland
Mikhail Nikolayevich Polyakov, Swiss Federal Laboratories for Materials Science and Technology, Switzerland
Johann Michler, Swiss Federal Laboratories for Materials Science and Technology, Switzerland
Xavier Maeder, Swiss Federal Laboratories for Materials Science and Technology, Switzerland

Key Words: fracture toughness, micro-cantilever, EBSD, TEM, plastic zone

The process zone or plastic zone around a loaded crack tip can significantly influence the fracture behavior of a material. Especially in micro-scale specimens, the plastic zone size may make out a large share of the sample volume and lead to a different fracture behavior than the one usually observed for macroscopic samples of the same material. Furthermore, the theoretical description of the plastic zone according to Irwin is not valid for single crystals. Therefore, a characteristic elastic-plastic fracture behavior is observed depending on crystallographic sample orientation and slip system activation. It is the aim of the study to understand the fracture process and behavior in micro-scale specimens in the presence of crack tip plasticity.

Notched micro-cantilevers were prepared by focused ion beam (FIB) milling in a tungsten single crystal. This material has nearly perfect elastic isotropy, a limited amount of activated slip systems and detailed knowledge of the macroscopic fracture behavior is available [1]. The cantilevers have dimensions of 25 µm in length, 5-7 µm in thickness and crack length to thickness ratios a/w of ca. 0.4. Loading rate and temperature are known to influence the fracture behavior decisively in bcc metals. Therefore displacement-controlled fracture tests were performed inside a scanning electron microscope in the temperature range between -150°C and 500°C. Applying the recently presented J-Integral technique [2] to plot continuous crack resistance curves, the fracture toughness and brittle-to-ductile transition (BDT) temperatures, which depend on the applied loading rate, were determined. This allows a thorough investigation of the activation energy of the BDT at the micro-scale.

Crack tip plasticity before and during crack growth was investigated by high-resolution electron backscatter diffraction measurements (HR-EBSD) on FIB cross-sections of the micro-cantilevers after mechanical testing. Plastic zones, which are strongly depending on the activated slip systems, and plastic strain gradients in terms of geometrically necessary dislocations were quantified and linked with the observed BDT behavior. Transmission electron microscopy was used to confirm the EBSD results and to provide dislocation analysis.

[1] P. Gumbsch, J. Riedle, A. Hartmaier, H.F. Fischmeister, Controlling Factors for the Brittle-to-Ductile Transition in Tungsten Single Crystals, Science. 282 (1998) 1293–1295.
[2] J. Ast, B. Merle, K. Durst, M. Göken, Fracture toughness evaluation of NiAl single crystals by microcantilevers - a new continuous J-integral method, Journal of Materials Research. 31 (2016) 3786–3794.